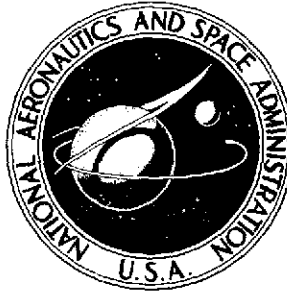


**NASA TECHNICAL  
MEMORANDUM**



**NASA TM X-3163**

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(NASA-TM-X-3163) VARIABLE COMBUSTOR  
GEOMETRY FOR IMPROVING THE ALTITUDE  
RELIGHT CAPABILITY OF A DOUBLE ANNULAR  
COMBUSTOR (NASA) 26 p HC \$3.75 CSCL 21E

**N75-13871**

**Unclas  
H1/07 06917**

**VARIABLE COMBUSTOR GEOMETRY  
FOR IMPROVING THE ALTITUDE RELIGHT  
CAPABILITY OF A DOUBLE ANNULAR COMBUSTOR**

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1. Report No. NASA TM X-3163		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle VARIABLE COMBUSTOR GEOMETRY FOR IMPROVING THE ALTITUDE RELIGHT CAPABILITY OF A DOUBLE ANNULAR COMBUSTOR				5. Report Date January 1975	
				6. Performing Organization Code	
7. Author(s) Donald F. Schultz				8. Performing Organization Report No. E-8058	
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135				10. Work Unit No. 501-24	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546				13. Type of Report and Period Covered Technical Memorandum	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract  A test program was conducted to evaluate several ways of improving the altitude relight capability of a double annular ram-induction combustor designed for Mach 3.0 cruise operation. Using various techniques including two modes of simulated combustor variable geometry, altitude relights were obtained down to a pressure of 3.6 newtons per square centimeter against 7.0 newtons per square centimeter for the unmodified combustor. This was at a test condition of 0.05 reference Mach number using ambient temperature inlet air and fuel.					
17. Key Words (Suggested by Author(s)) Variable geometry; Combustor (double annular); Combustor (annular); Altitude relight; Jet engine; Air swirlers; Flat spray fuel nozzles; Hollow cone spray fuel nozzles				18. Distribution Statement Unclassified - unlimited STAR category 07 (rev.)	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 25	
				22. Price* \$3.00	

\* For sale by the National Technical Information Service, Springfield, Virginia 22151

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SUMMARY

This test program was conducted to evaluate several methods, including several simulated variable geometry techniques, of improving the altitude relight capability of a double annular ram-induction combustor designed for Mach 3.0 cruise operation. The variable geometry techniques included simulated flapper valves in the combustor snout inlet to reduce snout airflow and simulated variable flow area in the outer transition liner to bypass air around the combustor during relight. The effects of some simple combustor modifications such as comparisons of axial flow and radial inflow air swirlers and flat spray against simplex hollow cone spray fuel nozzles were evaluated.

The greatest improvement in altitude relight capability was obtained with a combustor which used radial inflow air swirlers, hollow cone spray fuel nozzles, and simulated variable combustor geometry, which permitted air to bypass the combustor primary and secondary zones and enter at the upstream end of the outer exit transition liner. This combustor configuration provided altitude relights down to 3.6 newtons per square centimeter inlet total pressure compared to 7.0 newtons per square centimeter with the unmodified combustor at a test condition of 0.05 reference Mach number, with ambient temperature air and fuel.

## INTRODUCTION

This report presents the results of an effort to use simulated variable combustor geometry to improve the altitude relight performance of a double annular combustor. Previous testing of a short-length, double-annular, ram-induction combustor (refs. 1 and 2) indicated a serious altitude relight problem. Relight could not be obtained with an 80 K minimum temperature rise, at inlet-air pressures below 6.2 newtons per square centimeter at ambient air temperatures and reference Mach numbers above 0.05.

The previous testing indicated that the altitude-relight performance was very sensitive to reference Mach number. Decreasing the reference Mach number improved relight performance. Variable combustor geometry could be used on engines to redirect the airflow during altitude relight. However, as an alternative, if the combustor were optimized for altitude relight, then diffuser bleed (ref. 3) could be used to redirect the airflow for all other operating conditions. Because the double-annular combustor has the unique feature that combustion can be maintained in either annulus independent of the other, several methods seem possible to improve relight performance by reducing the reference Mach number in the outer annulus while maintaining the same diffuser inlet Mach number.

The present investigation was conducted to evaluate several variable combustor geometry techniques to determine if variable geometry can be used to improve the altitude relight capability of a double-annular combustor by reducing airflow in the outer annulus which contains the ignitors. Simulated variable geometry configurations investigated were: (1) punched plate air restrictors to simulate flapper doors at the combustor snout inlet, (2) shortened outer exit transition liner length to simulate a translating liner to permit bypassing air around the burning zone, and (3) inlet airflow distortion plates to simulate a naturally distorted diffuser inlet air velocity profile which would be flattened with the use of diffuser bleed for all other engine operating conditions. Tests were conducted to determine relight capability over a range of inlet pressures from 2.4 to 10.0 newtons per square meter (3.5 to 14.5 psia), inlet air temperatures of 284 to 300 K ( $51^{\circ}$  to  $80^{\circ}$  F), overall reference Mach number of 0.05, and fuel air ratios from 0.006 to 0.045.

## TEST COMBUSTOR

### Combustor Design

The combustor is referred to as a double-annular, ram-induction combustor. The double-annular design permits a considerable reduction in combustor length while maintaining an adequate ratio of length-to-annulus height. The ram-induction principle utilizes the kinetic energy of the inlet air to provide rapid mixing both in the primary zone and in the secondary zone. The advantages of this combustor are a shorter combustor length, a shorter diffuser length, and a reduction in the film-cooling-air requirement. A cross section of the combustor may be seen in figure 1. Figure 2 shows photographs of the combustor.

The combustor has 64 fuel nozzles, 32 in each annulus. In addition, there are two ignitors located in the outer annulus, 180° apart. Each ignitor was supplied by a 20-joule capacitance discharge power supply. A more detailed description of this combustor and the ram-induction concept may be found in reference 2.

### Combustor Configurations

Ten combustor configurations were tested besides the baseline model. These models consisted of various combinations of three basic variable geometry concepts, a comparison of axial and radial inflow air swirlers and a comparison of hollow cone and flat spray fuel nozzles. The variable geometry concepts simulated are: flapper valves on the snout inlet, translating outer diameter exit transition liner, and inlet airflow distortions which redirected the diffuser inlet airflow during relight.

Snout inlet flapper vane simulation. - The simulation of snout inlet flapper vanes was accomplished by welding punched plate to the combustor snout inlet lips shown in figure 3. In actual engine application a series of vanes (flappers) would rotate from a position perpendicular to the airstream at light-off to a position parallel to the airstream during engine acceleration to idle. The intent of these vanes is to reduce the airflow entering the combustor through the headplate including air swirlers thus reducing the effective reference velocity in the combustor primary zone. This concept is used in models 6-2B, 6-2BO, 6-2BI, 6-2BF, 6-3B, and 6-4B which are specified on the combustor configuration flow diagram figure 4.

Translating outer exit transition liner simulation. - The simulation of a translating outer exit transition liner was made by utilizing an exit transition liner that was shorter than the conventional liner. Pins were welded to the forward end of this shortened exit transition liner so it would connect to the rub-ring at the rear of the double annular combustor as shown in figure 5. In an actual engine application one segment of outer exit transition liner would translate axially exposing a similar gap. The liner segment would translate closed after acceleration to idle. Another method would use a series of doors which would open up into the airstream between the outer liner and the housing thus capturing dump air. A third idea would employ a circumferential ring which would rotate a few degrees exposing or closing air dump holes.

The intent of this air dumping technique is to reduce the effective reference Mach number in the outer combustor annulus thus encouraging better relight performance. This technique was used on models 6-4, 6-4B, and 6-4I of figure 4.

Diffuser inlet distortion simulations. - Punched plate extending perpendicularly from either wall into the constant area section of the diffuser inlet was found to be satisfactory for simulating a distorted diffuser inlet air velocity profile. Figure 6 shows the axial location of the distortion plates while figure 7(a) shows the actual inlet airflow distortion plates, and figure 7(b) shows the inner plate installed. The punched plates had 29 percent open area with 0.084-centimeter holes, and were 0.061 centimeter thick. The support backing plate is 0.318 centimeter thick and 1.905 wide. The outer diameter plate was 0.968 centimeter wide (extension from wall of diffuser) while the inner diameter plate was 1.286 centimeters wide. The plates were made in segments. They were installed with pins extending from the outer housing to the inner diameter housing and located behind diffuser inlet struts.

For these tests, three inlet velocity profiles were used; namely, flat, tip peaked (peaked toward the outer diameter), and hub peaked (peaked toward the inner diameter). These diffuser inlet velocity profiles are shown in figure 8.

In an actual engine application any natural inlet velocity distortion coming from the compressor would be exploited (ref. 4). After ignition diffuser bleed (ref. 3) would be used to trim the inlet air profile to meet the normal combustor performance requirements. The purpose of distorting the inlet airflow is to help bypass air around the primary combustion zone to reduce the effective reference Mach number in that zone. These distortions were used in models 6-2BO, 6-2BI, and 6-4I of figure 4.

Air swirlers used in this comparison testing. - Figure 9 shows the radial inflow and axial flow air swirlers used in this study. The radial inflow swirlers flowed about 60 percent less airflow than the axial flow swirlers at the same differential pressure. Testing at simulated engine idle conditions (ref. 5), indicated significantly better performance with radial inflow air swirlers than with axial flow swirlers when both swirlers have similar flow characteristics. Assuming this effect would persist, the radial inflow air swirlers were manufactured with a reduced flow area compared to the axial swirlers to further reduce primary zone effective reference velocity.

Fuel nozzles. - Hollow cone spray fuel nozzles with an  $80^\circ$  spray angle were used with all models except one, model 6-2BF. In this model, flat spray nozzles with an  $80^\circ$  spray angle at 28 newtons per square centimeter differential pressure were used. Figure 10 shows the fuel flow characteristics of these nozzles.

## TESTING PROCEDURE

The data were obtained in the following sequence: First, the combustor was operated at a condition that ensured ignition. Upon ignition the combustor fuel flow was adjusted to give the highest possible temperature rise with airflow, inlet temperatures, and pressure remaining constant.

Holding fuel air ratio approximately constant, the airflow and pressure were reduced at constant reference Mach number and inlet-air temperature. At the new pressure level, the fuel-air ratio was again ranged to determine the maximum temperature rise. Data were taken at successively lower pressures at constant inlet-air temperature, reference Mach number, and fuel-air ratio giving the highest temperature rise until the combustor average temperature rise dropped below 80 K. As long as the combustor maximum temperature rise was below 80 K, the combustor was classified as blown out or unlit. This temperature rise was considered the minimum temperature rise necessary to accelerate an engine and therefore any temperature rises less than 80 K were considered the same as zero temperature rise. The fuel-air ratio which gave the maximum temperature rise was defined as the optimum fuel-air ratio. Once the temperature rise dropped below 80 K the combustor was extinguished. Ignition was then attempted, and the fuel-air ratio was ranged about the optimum fuel-air ratio. If ignition with 80 K temperature rise was not achieved

at that condition, the pressure was increased at constant reference Mach number and inlet-air temperature until ignition was obtained.

This procedure differs somewhat from that used in reference 1 in that in reference 1 blowout was defined as zero temperature rise and relight as any temperature rise when obtained on an ignition attempt.

### Test Facility and Instrumentation

The altitude-relight capabilities of the combustor were studied in a closed-duct test facility. A flow path of this facility is shown in figure 11. Airflow rates for combustion from 2.3 to 136 kilograms per second at pressures from 1.7 to 103 newtons per square centimeter, could be cooled to 280 K or heated to 922 K without vitiation before entering the combustor. Ambient temperature fuel was used.

Figure 6 shows the axial location of the instrumentation stations and the placement of the airflow distortion plates.

Combustor-outlet total temperature and pressure were measured at  $6^\circ$  increments around the exit circumference. At each  $6^\circ$  increment, five temperature and pressure points were measured across the annulus.

### RESULTS AND DISCUSSION

In this study, ten double annular combustor configurations using three forms of simulated variable geometry were tested. In addition, comparisons of radial inflow with axial flow air swirlers and flat against hollow cone, fuel spray nozzles were made. Figure 12 shows the results of these tests as well as table I, which summarizes the configurations and results. Figure 12 shows that model 6-4B, the model with the short outer diameter transition liner, 25 percent open area punched plate across the snout inlet, and radial inflow air swirlers gave the best altitude relight improvement. Ignition with a minimum of 80 K combustor temperature rise was obtained at a reference Mach number of 0.05, an inlet air temperature of 285 K, and 3.6 newtons per square centimeter inlet total pressure. This compares with 7.0 newtons per square centimeter for model 6-1, the original model with no modifications and with 9.7 newtons per square centimeter for model 6-2BF the worst configuration tried. The curve in figure 12 is taken from figure 11(b) of reference 1. The curve



is the minimum pressure at which relight could be obtained with 100 K combustor average temperature rise on a similar double annular combustor at the same reference Mach number and fuel temperature. The combustor of reference 1 differed somewhat from the model 6 series combustors reported here, in that that combustor contained twice as many ram induction air scoops and slightly higher total pressure loss than the model 6 series combustors.

Figure 13 shows the combustor pressure required to obtain a given combustor temperature rise for many of the configurations tested. Figure 13 also indicates that model 6-4B has good acceleration characteristics as indicated by the relatively flat slope of its pressure-temperature curve compared to the other models. A 0.5-newton-per-square-centimeter increase in combustor total pressure resulted in a 240 K increase in combustor average temperature rise with model 6-4B, compared with only 120 K increase in combustor average temperature for the next best configuration with the same inlet total pressure rise.

#### Effects of Individual Modifications

Comparison of axial flow and radial inflow air swirlers. - Comparing models 6-1, (axial air swirlers), to model 6-3, (radial inflow air swirlers) figure 12, indicates significant improvement in altitude relight capability was achieved. Model 6-3 had a relight capability down to 4.7 newtons per square centimeter with combustor surge (ignition associated with unstable very rapid increases in inlet pressure and combustor temperature rise) compared to 7.0 newtons per square centimeter for model 6-2 without surge. The ignition fuel-air ratio of model 6-3 was about 0.040 at the 4.7 newtons per square centimeter relight condition. Whether the engine would accelerate very rapidly or be damaged by such a surge would have to be tested further probably in an actual engine. Models 6-4, 6-4B, and 6-4I also used the radial inflow air swirlers with no surge problem and relight performance superior to model 6-1.

Comparison of flat spray and hollow cone spray fuel nozzles. - The spray from flat spray fuel nozzles was found to rotate about its central axis when the air from the radial inflow air swirlers impinged on the spray. A rotation of more than  $90^{\circ}$  was obtained with less than 1.4 newtons per square centimeter differential pressure across the air swirler with ambient pressure discharge. Thus, this combination of nozzle and swirler is certainly unsuitable because fuel impingement on the combustor

liners would likely result from such a rotation. The flat spray fuel nozzles with axial flow swirlers formed a solid cone fuel spray. There appeared to be about equal fuel flow per unit area within the cone. The hollow conical spray, nozzles sprayed with a "thick walled" conical spray when the swirler air was added against a "thin wall" spray with no airflow. This same result was obtained with either the radial inflow or the axial flow air swirlers.

The flat spray fuel nozzles used in these tests were sized considerably larger than the "low flow" simplex nozzles as indicated in figure 10. This flow range difference can lead to a distorted conclusion concerning the relight capability of the flat spray fuel nozzles. There are indications that if flat spray nozzles of the same flow range as the "low flow" hollow cone spray fuel nozzles were used, relights would occur at somewhat lower pressures than with the hollow cone nozzles. This conclusion results from a test with "medium flow" hollow cone spray nozzles, which being of lower flow range than the flat spray nozzles, did not perform as well as the flat spray nozzles.

Simulated variable snout inlet. - Reducing the snout airflow area by 75 percent as shown in figure 3 improved the altitude relight capability by 1.5 newtons per square centimeter. When model 6-1's snout airflow was reduced 75 percent creating model 6-2B (see fig. 4), relights were obtained at 5.5 newtons per square centimeter against 7.0 newtons per square centimeter for model 6-1. Likewise when model 6-4's snout flow was reduced by 75 percent creating model 6-4B, relights were obtained at 3.6 newtons per square centimeter against 5.1 newtons per square centimeter for model 6-4. However, when the snout blockage was added to model 6-3 creating model 6-3B the relight capability deteriorated by 1.5 newtons per square centimeter in the relight with surge mode.

Simulated traversing outer diameter exit transition liner. - This simulation was made by installing an outer diameter exit transition liner that provided a 2.0-centimeter gap between the combustor and the upstream end of the outer exit transition liner as shown in figure 5. Model 6-4, model 6-3 with short exit transition liner used, was able to relight at 5.1 newtons per square centimeter with stable combustion compared to 8.1 newtons per square centimeter for model 6-3. However, in one case a 0.4 newton per square centimeter deterioration in performance was found. Therefore, caution must be used in applying this method of altitude relight improvement.

Simulated distorted inlet airflow. - Punched plate was installed off either the outer or the inner diffuser inlet wall to create a distorted inlet air profile similar to what is often found or could be created from a compressor exit. This type of modification did not improve performance of model 6-2B. Both models 6-2BO, model 6-2B with outer wall distortion plate installed, and model 6-2BI, model 6-2B with inner wall distortion plate installed, had poorer relit performance than model 6-2B. They relight at up to 0.9 newton per square centimeter higher pressure than model 6-2B. However, model 6-4I relit at 0.3 newton per square centimeter lower pressure than model 6-4. So some improvement is possible.

### SUMMARY OF RESULTS

Several methods of improving the altitude relight performance of a double annular ram-induction combustor were evaluated and found to provide varying degrees of improvement. All testing was conducted with a reference Mach number of 0.05 using ambient temperature air and fuel. A temperature rise of 80 K was used as a criteria for relight. At a temperature rise less than 80 K, the combustor was considered unlit.

Variable combustor geometry was found to have significant potential in reducing altitude relight problems. Using a combustor configuration which simulated a translating outer diameter exit transition liner and variable area combustor snout inlet, relights were obtained down to 3.6 newtons per square centimeter inlet total pressure against 7.0 newtons per square centimeter for the unmodified combustor. This configuration also utilized radial inflow air swirlers which provided relights up to 2.3 newtons per square centimeter lower pressures than axial flow air swirlers.

Lewis Research Center,

National Aeronautics and Space Administration,

Cleveland, Ohio, September 26, 1974,

501-24.

## APPENDIX A

### SYMBOLS

**P**      pressure  
**T**      temperature

#### Subscripts:

**s**      static  
**t**      total  
**3**      diffuser inlet  
**4**      combustor exit

## APPENDIX B

### CALCULATIONS

#### Reference Mach Number

The reference Mach number was computed from the total airflow, air density at the diffuser inlet, and reference area. The actual combustor reference area is 0.428 square meter, the minimum cross-sectional area into which the combustor will fit. However, this combustor was designed to operate in an engine that had a combustor reference area of 0.448 square meter. The reference Mach number was computed using the larger area. Therefore, all pressures, temperatures, and airflows were consistent with the altitude windmill operation of that engine.

#### Units

The U.S. Customary system of units was used for primary measurements and calculations. Conversion to SI units (System International d'Unités) is done for reporting purposes only. In making the conversion, consideration is given to implied accuracy and may result in rounding off the values expressed in SI units.

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1. Schultz, Donald F.; Mularz, Edward J.: Factors Affecting Altitude Relight Performance of a Double-Annular Ram-Induction Combustor. NASA TM X-2630, 1972.
2. Perkins, Porter J.; Schultz, Donald F.; and Wear, Jerrold D.: Full-Scale Tests of a Short Length, Double-Annular Ram-Induction Turbojet Combustor for Supersonic Flight. NASA TN D-6254, 1971.
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4. Rusnak, J. P.; and Shadowen, J. H.: Development of an Advanced Annular Combustor. PWA-FR-2832, Pratt & Whitney Aircraft (NASA CR-72453), 1969.
5. Schultz, Donald F.: Modifications That Improve Performance of a Double Annular Combustor at Simulated Engine Idle Conditions. NASA TM X-3127, 1974.

TABLE I. - COMBUSTOR CONFIGURATIONS TESTED

Model	Change	Purpose	Result	Ignition	
				Pressure, N/cm <sup>2</sup>	Temperature K
6-1	Original model	Baseline Data	-----	7.0	293
6-2B	Installed 25 percent open area punched plate to snout simulating variable inlet area snout	To reduce effective reference velocity in primary zone of combustor	Moderate improvement	5.5	284
6-2BO	Model 6-2B with addition of outer diameter inlet airflow distortion punched plate	To further reduce effective reference velocity in outer annulus	Less successful than model 6-2B	6.4	290
6-2BI	Model 6-2B with addition of inner diameter inlet airflow distortion punched plate	To further reduce effective reference velocity in inner annulus	Less successful than model 6-2B but better than model 6-2BO	6.1	287
6-2BF	Model 6-2B flat spray fuel nozzles rather than conical spray simplex fuel nozzles	To evaluate effect of flat spray fuel nozzles	Very much worse than original model 6-1	9.7	284
6-3	Model 6-1 with radial inflow air swirlers having 1/2 airflow area as axial flow swirlers of model 6-1	To compare effects of radial inflow air swirlers to those of axial flow swirlers	Better performance than model 6-2B on surge lightoff	<sup>a</sup> 4.7	288
				<sup>b</sup> 8.1	291
6-3B	Model 6-3 with 25 percent open area punched plate added to snout as in model 6-2B	To further reduce effective reference velocity in primary zone of combustor	Moderate improvement over model 6-1	<sup>a</sup> 6.2	295
6-4	Model 6-3 with outer diameter exit transition liner shortened to provide bypass air gap at front end of exit transition liner	To bypass air around primary and secondary combustion zones to reduce effective reference Mach number in these zones	Good lightoff	5.1	299
6-4B	Model 6-4 with 25 percent open area punched plate added to snout as in model 6-2B	To bypass additional air around primary zone	Best relight performance	3.6	285
6-4I	Model 6-4 with addition of inner diameter inlet airflow distortion punched plate	To determine if model 6-4B performance could be obtained with inlet airflow distortion rather than snout airflow restriction	Not as good as model 6-4B	4.8	300

<sup>a</sup>Surge on lightoff.<sup>b</sup>With stable combustion.REPRODUCIBILITY OF THE  
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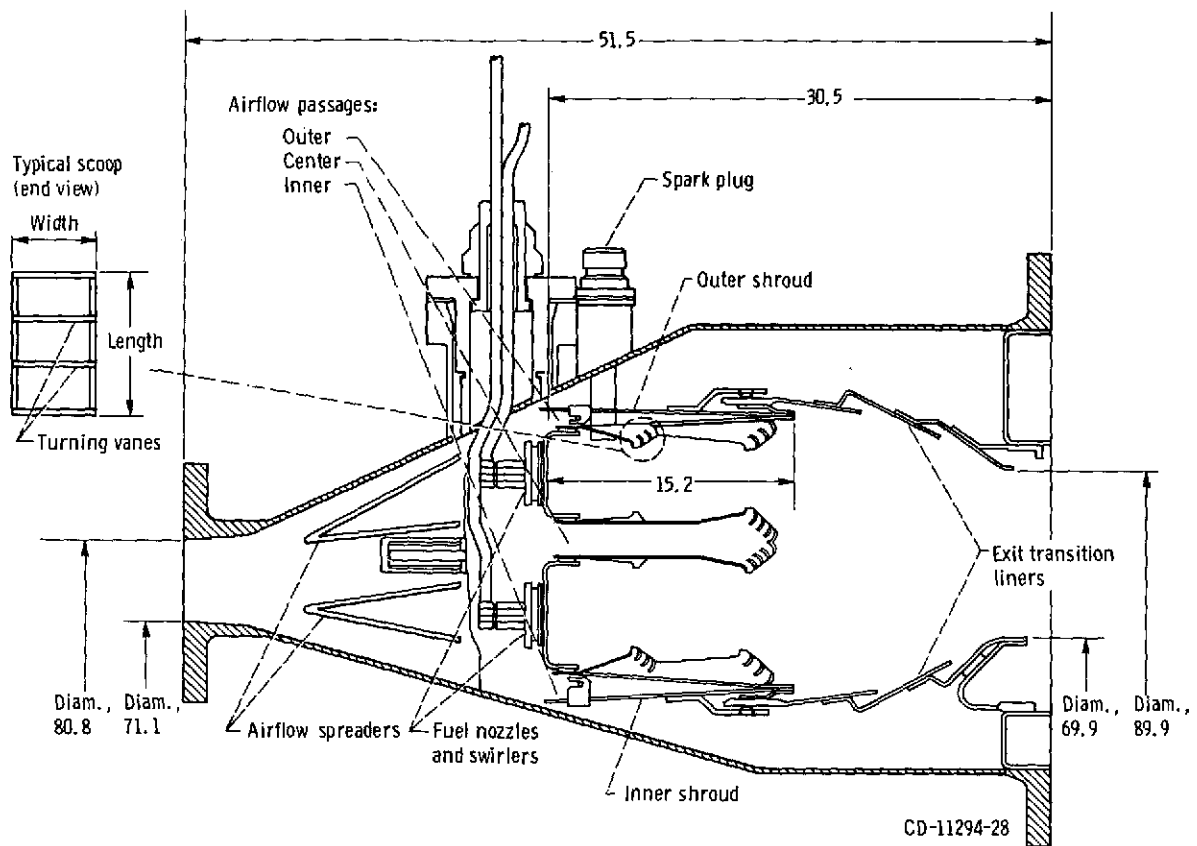
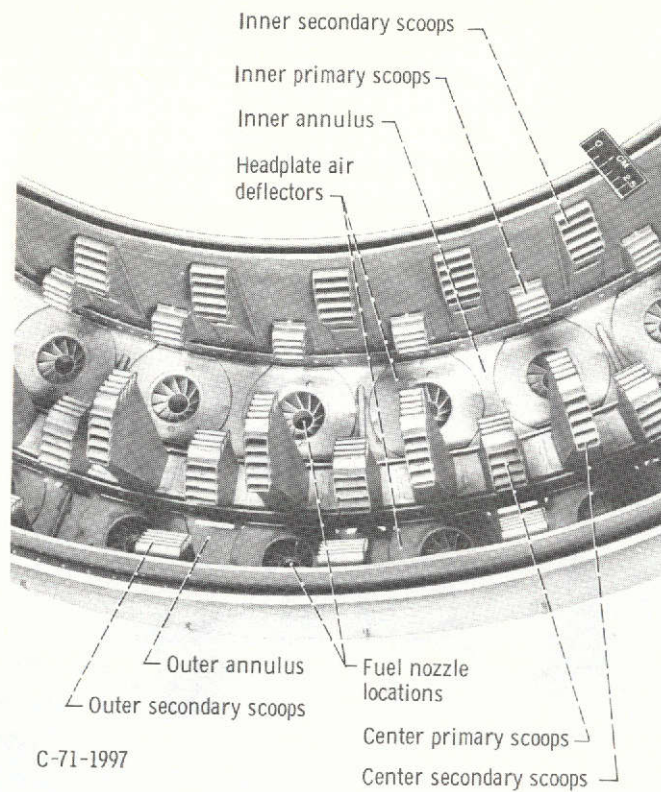
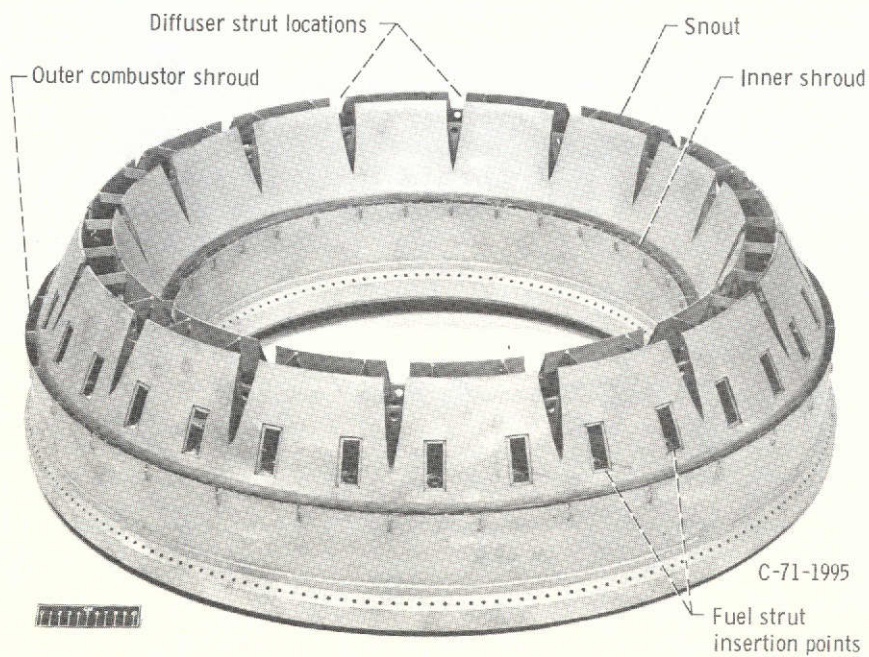


Figure 1. - Cross section of double-annular ram-induction combustor. (All dimensions are in cm.)





(a) Closeup view looking upstream.



(b) Looking downstream (exit transition liners removed).

Figure 2. - Double-annular ram-induction combustion.

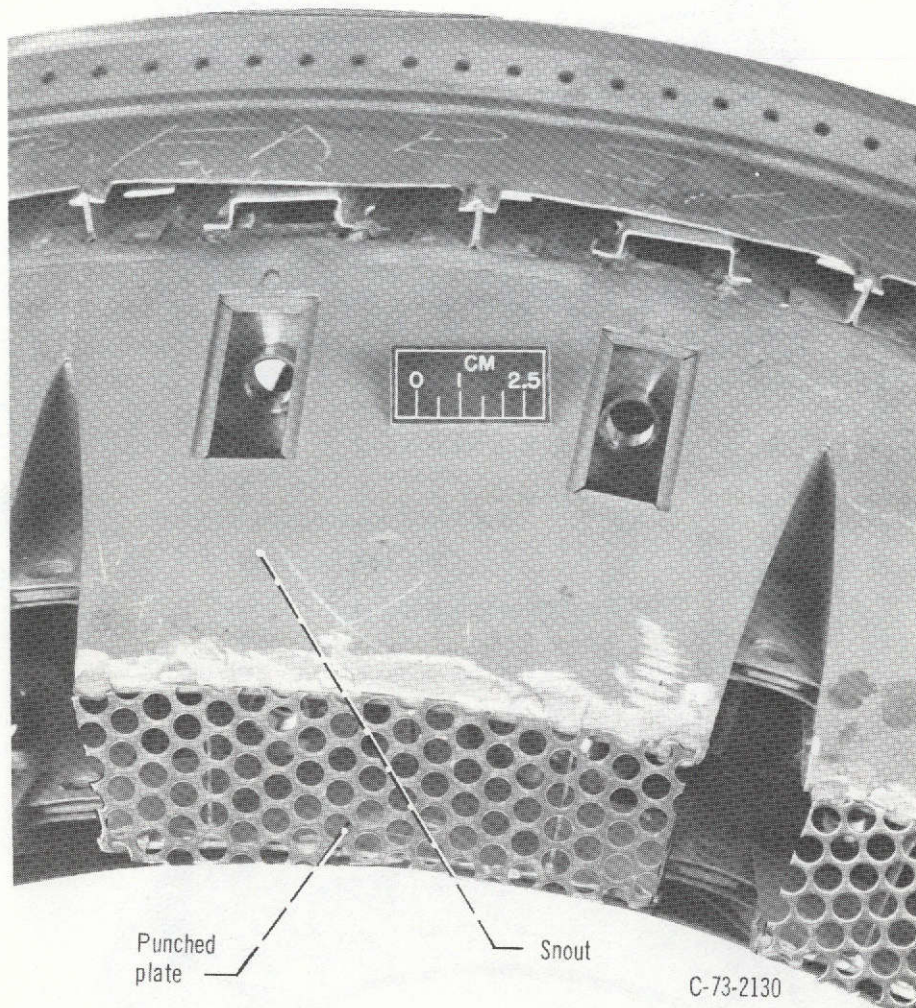


Figure 3. - Snout inlet flapper valve simulation.

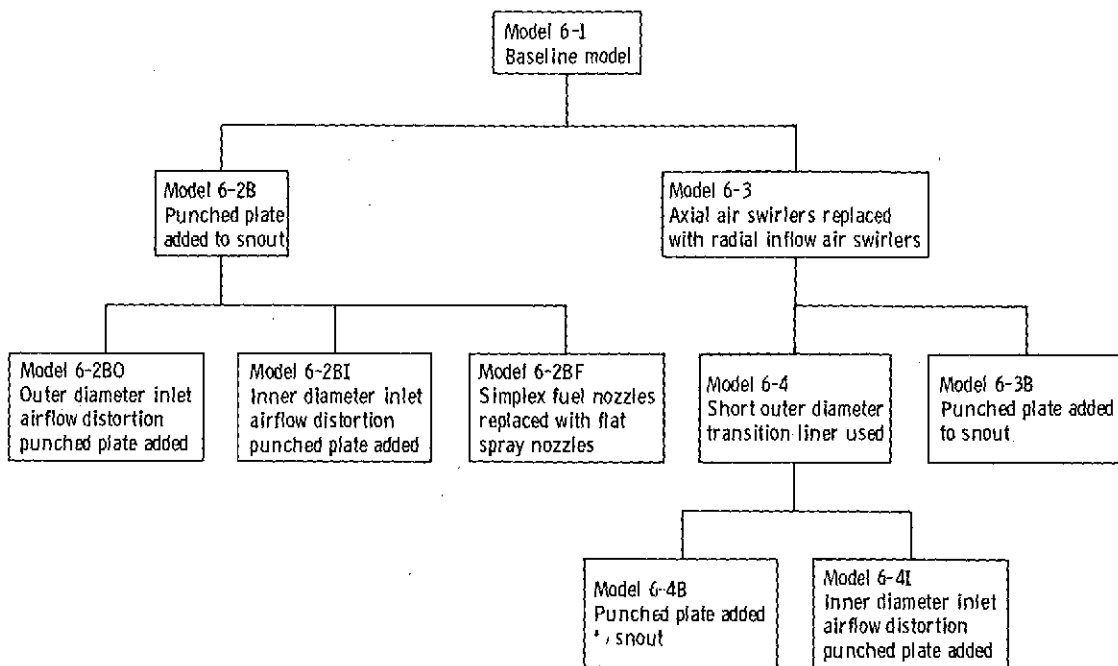
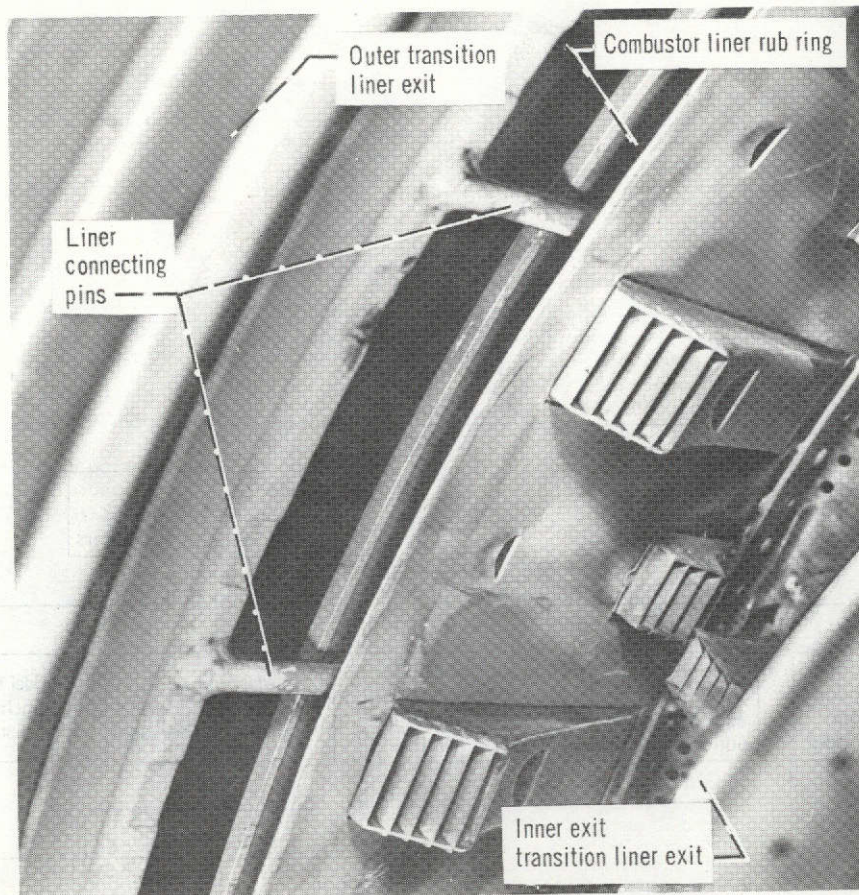


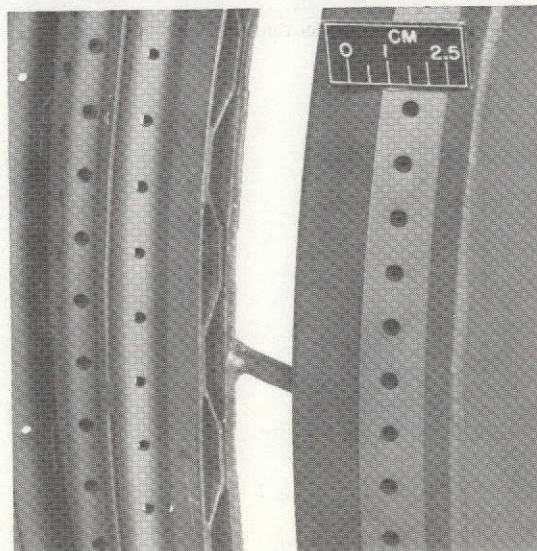
Figure 4. - Combustor configuration flow diagram.

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(a) View looking upstream from inside combustor exit.



(b) Exterior view looking downstream.

Figure 5. - Translating outer diameter exit transition liner simulation.

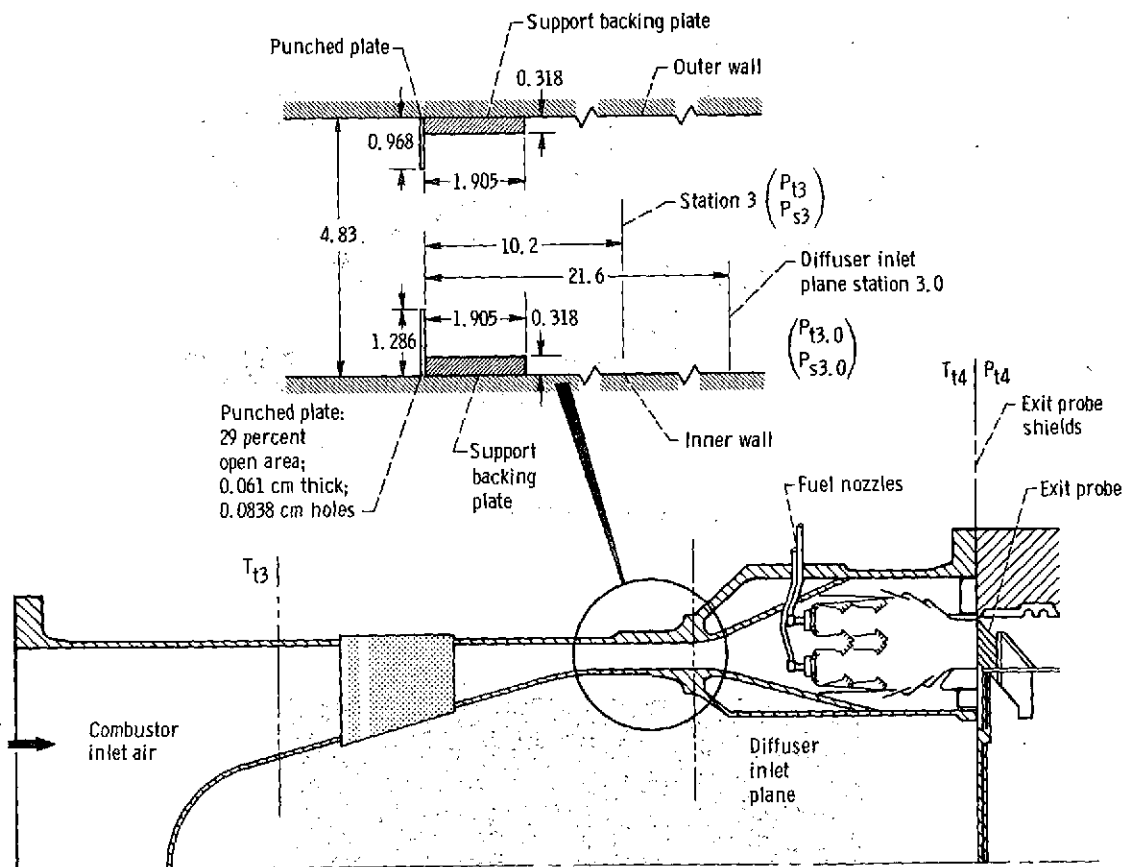
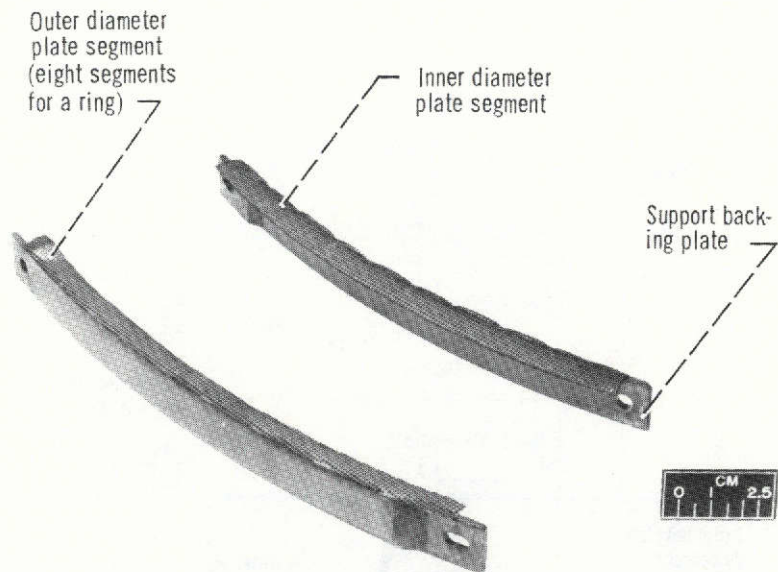
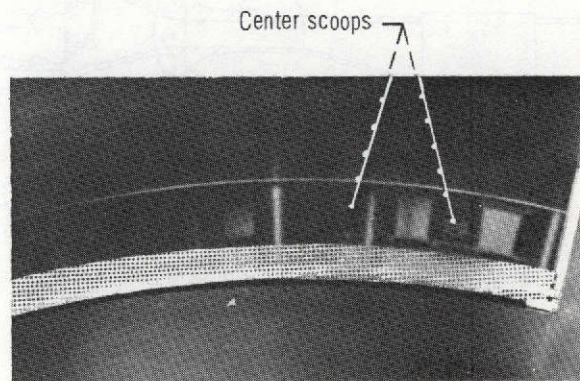


Figure 6. - Axial location and detailed dimensions of diffuser inlet airflow distortion plates.



(a) Inlet airflow distortion plates.



(b) Inner diameter airflow distortion plate installed looking downstream.

Figure 7. - Diffuser inlet distortion simulation plates.

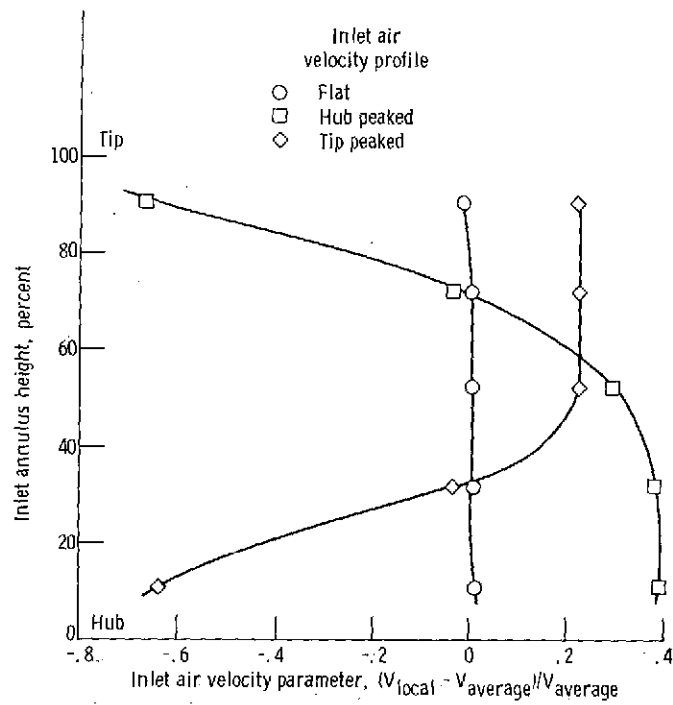


Figure 8. - Diffuser inlet annulus height against inlet velocity parameter. Average inlet velocity, 72 meters per second.



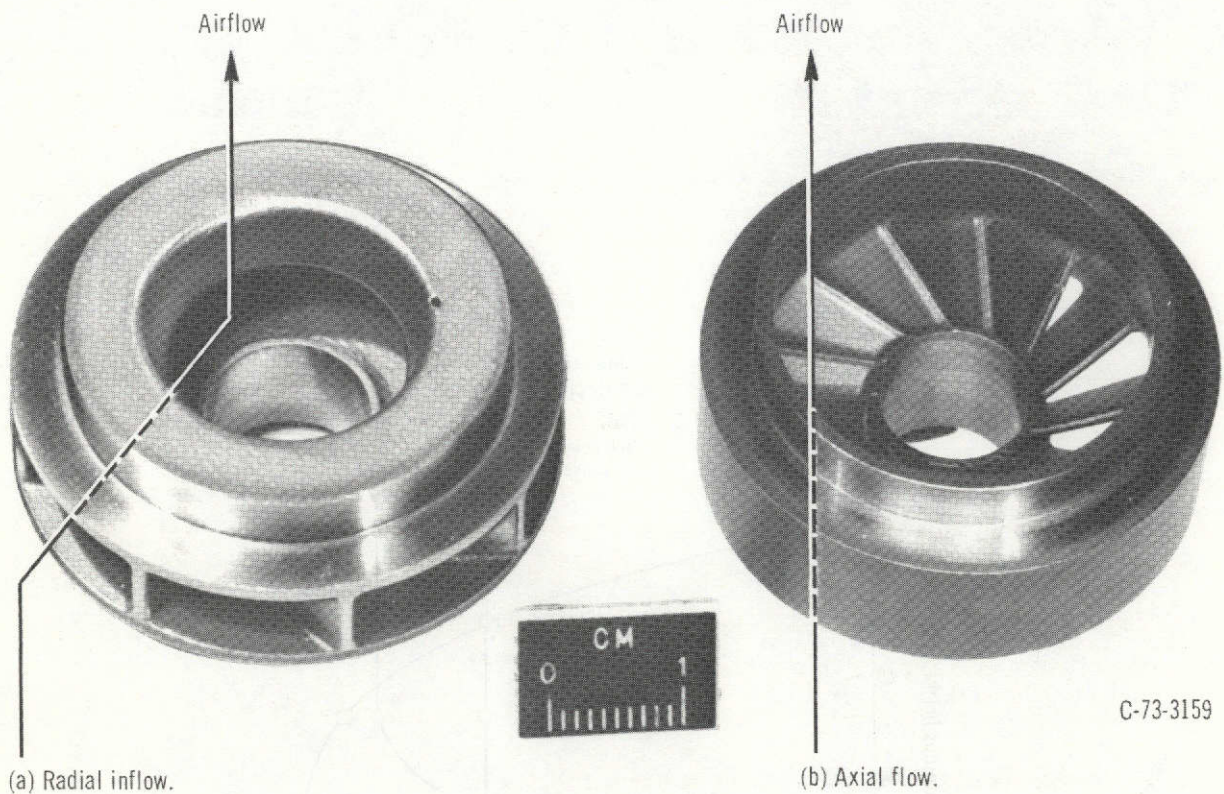


Figure 9. - Comparison of radial inflow and axial flow air swirlers used in this study.

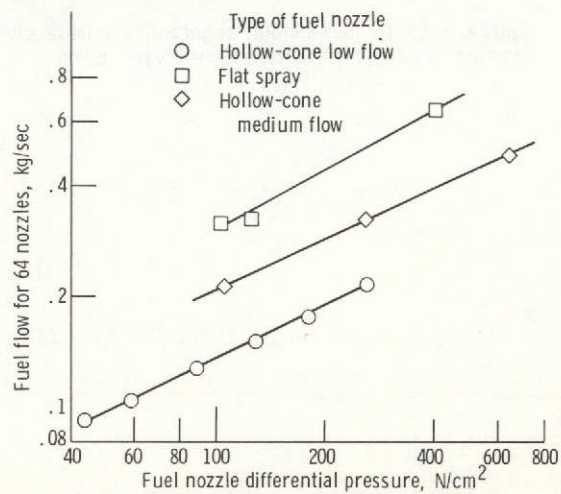


Figure 10. - Fuel flow against fuel nozzle differential pressure for hollow-cone and flat spray fuel nozzles.



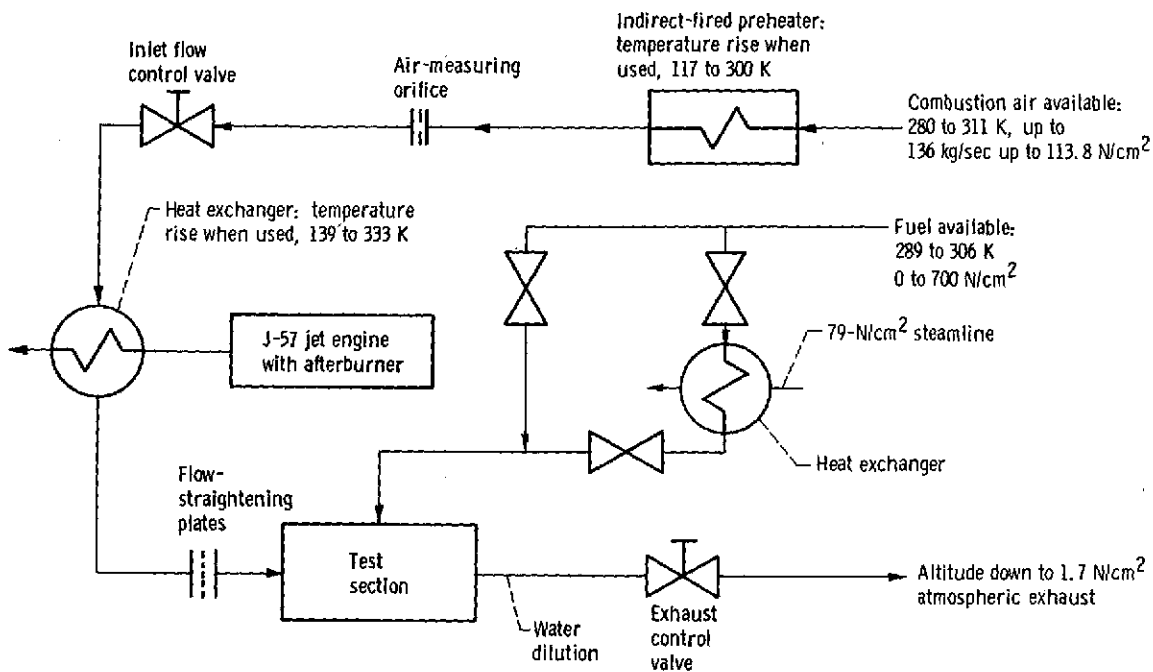


Figure 11. - Schematic of test facility combustion air and fuel.

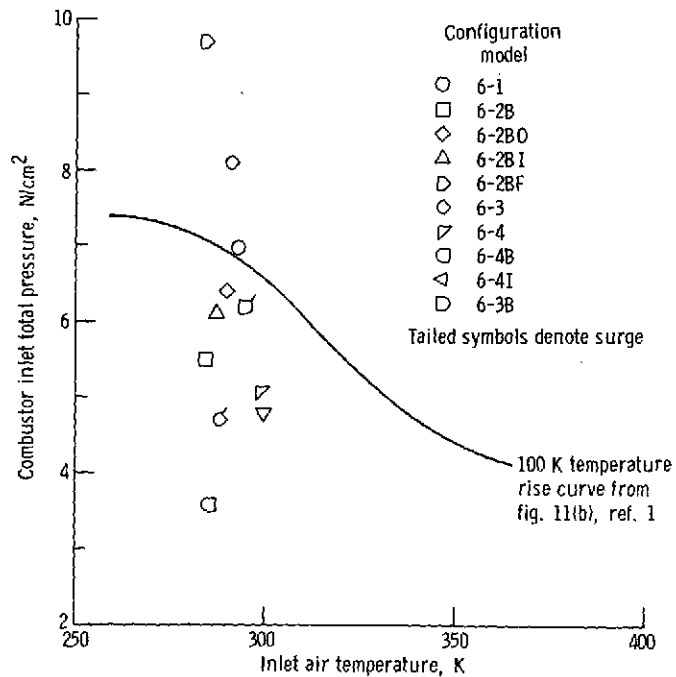


Figure 12. - Altitude relight performance of configurations tested at reference Mach number of 0.05 and minimum combustor temperature rise of 80 K.

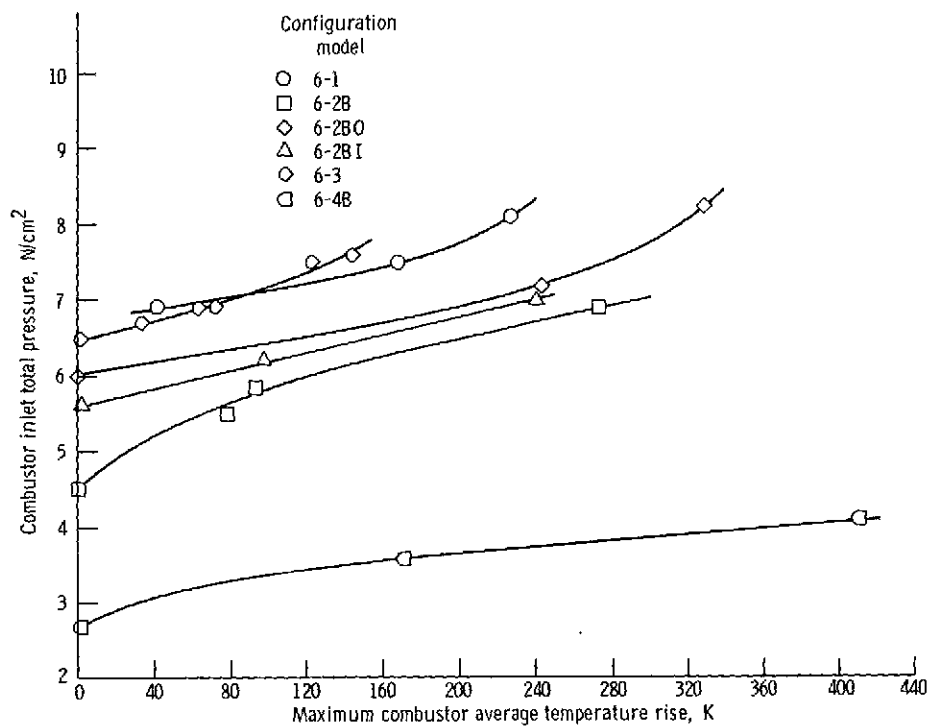


Figure 13. - Influence of combustor pressure on maximum possible temperature rise. Inlet temperature of 290 K and reference Mach number of 0.05.